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HIGH-TEMPERATURE ELECTRIC CONNECTORS

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The paper presents information on the design peculiarities of high-temperature electric connectors, including vacuum-tight connectors.

Due to the persistent tendencies toward an increase in the operating temperatures of power plants (automobile engines, aircraft engines, etc.) with a view to increasing their efficiency and providing for the minimum possible weight and dimensions parameters, regulation and control equipment is placed directly on the structural elements of power engines, often in areas with increased temperatures.

The need arose to develop control and regulation equipment that operates efficiently at temperatures of 200 – 250°C and above, as well as in zones of sign-variable mechanical loads of varying intensity. As a consequence, it became necessary to develop switching equipment (electric connectors) that function reliably in severe operating conditions which significantly decrease the reliability of the connectors due to oxidation of the contacting surfaces of pin and socket by atmospheric oxygen, and due to a decrease in the contacting force as a result of loss of elastic properties by the spring elements of the socket. Application of plastics and rubber in these conditions (elastic elements, sealing elements, insulators) is problematic.

Therefore, the traditional materials (plastics, rubber, sealers, aluminum and copper alloys) used in electric connectors for general industrial purposes are being replaced by new materials: glass, devitrified glass, ceramics, polymers with ceramic fillers, and ceramic cements, and also stainless steel, heat-resistant bronze, alloys of molybdenum and rhenium, precision alloys with a preassigned thermal coefficient of linear expansion, titanium alloys, and alloys with a "shape memory" effect.

There are corresponding modifications evident in the manufacturing technologies for making pieces of the materials listed above and in the equipment used in the process.

A need for specialized machinery and tools arose as well, since the technological processes require a development and

maintenance of temperatures of the order of 1000 – 2000°C with a high degree of accuracy. In this case, the elements are protected from corrosion by gas media (argon, nitrogen, hydrogen) or a vacuum.

The new type of electric connectors is represented by high-temperature electric connectors (HEC), successfully used, for example, in power plants or in telemetric devices for deep drilling of wells.

Another variety of HEC is a vacuum-tight high-temperature electric connector whose structural elements are made of vacuum-tight materials. This feature of HEC design makes it possible to use it, for example, in the barriers separating the atmosphere from a deep vacuum, including a space vacuum.

The data on HEC in the literature mostly concern glass-to-metal seals with respect to the development of hermetic plugs, including plugs allowing for permissible helium leakage.

The purpose of the present paper is to summarize the data on HEC and to make equipment designers acquainted with the structural peculiarities of these connectors and their main specifications and service conditions.

In their structural design, methods providing for contact reliability, and installation, HEC represent the further evolution of general purpose electric connectors [1 – 3].

HEC are classified as hermetic and non-hermetic. Hermetic connectors consist of a hermetic plug and non-hermetic socket, in non-hermetic connectors both socket and plug are non-hermetic.

Hermetic plugs are fixed on a piece of equipment (on hermetic partitions), usually employing argon-arc welding which produces a vacuum-tight seal.

The fastening of non-hermetic plugs, with minor exceptions, is the same as fastening of general-purpose industrial plugs. The electrical installation of HEC is complicated by the necessity of using heat-resistant (rigid) wires, including cables with metal sheathing.

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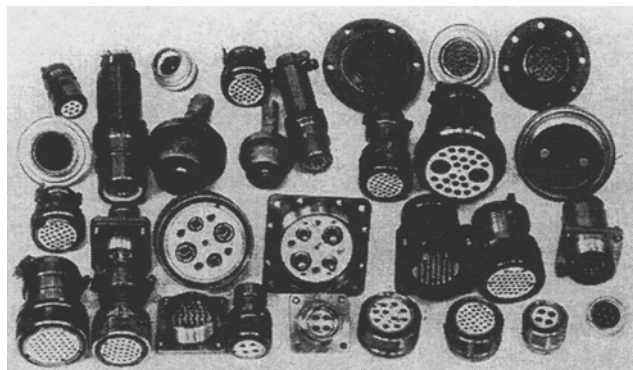


Fig. 1. High-temperature electric connectors.

The connection of wires and cables to contact tails is done by soldering employing high-temperature silver-based solders, argon arc and laser welding, as well as crimping.

The temperature scale of HEC media is as follows: 250, 315, 400, and 500°C.

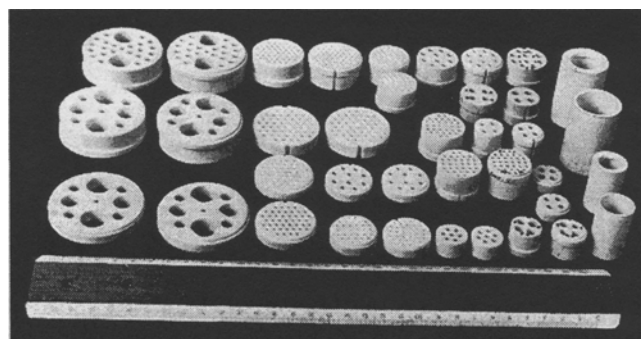


Fig. 2. Ceramic insulators of non-hermetic HEC.

Several companies in USA, France, and Switzerland are developing and producing HEC. The working temperature scale of these HEC is: 250, 350, 659, 1093°C.

In the case of high temperatures, their duration is limited to 20 min, or it is recommended that a shielding gas environment or a vacuum be employed.

TABLE 1

Maximum working temperature, °C	Environment	Permissible leakage value (helium) for hermetic plugs, 10^{-5} Pa · cm ³ /sec	Material					Method of cable sealing
			Plug material			Socket material*		
			Pin, coating	case, coating	insulator	Pin jack, coating, elastic element	case, coating	
380	Air, pressure below 133 μPa	Not more than 5	Nickel alloy, nickel		Glass S 72-4	Bronze, nickel, alloy with elastic properties	Titanium alloy, oxidation	Soldering
280	Air	The same	The same		The same	The same	The same	The same
250	The same	The same	The same		The same	The same	The same	The same
200	The same	The same	The same		The same	The same	The same	The same
200	The same	The same	Alumel, chromel without coating	Stainless steel	Glass composition**	Alumel, chromel without coating, alloy with elastic properties	The same	The same
200	The same	The same	Copper, gold over nickel	Nickel alloy	Glass S 72-4	Bronze, gold over nickel, alloy with elastic properties	The same	Crimping, bolt fastening
380	Air, pressure below 133 μPa	Non-hermetic	Bronze, nickel	Titanium alloy, oxidation	Ceramics	Bronze, nickel, alumel, chromel without coating, alloy with elastic properties	The same	The same
510	Shielding gas, pressure 11 MPa	Not more than 5	Molybdenum alloy, nickel	Titanium alloy, without coating	Glass S 48-4	Bronze, nickel, alloy with elastic properties	The same	The same
380	Air, pressure below 133 μPa	Non-hermetic	Bronze, nickel, alumel, chromel without coating	Titanium alloy, oxidation	Ceramics	Bronze, nickel, alumel, chromel without coating, alloy with elastic properties	The same	Crimping, inserted contacts
345	Air	The same	Nickel alloy, gold over nickel	The same	The same	Nickel alloy, gold over nickel, alloy with elastic properties	The same	Crimping, removable contacts
350	The same	Not more than 5	Nickel alloy, nickel		Glass C 66-2	Nickel alloy, gold over nickel	Titanium alloy, oxidation, stainless steel	Laser welding

* The insulator is made of ceramics in all instances.

** According to USSR Inventor's Certificate 620441.

Insulators are made of glass and ceramics or, more rarely, of ceramics and synthetic mica with glass. Materials for contact couples are: alumel, chromel without coating, molybdenum coated with chrome, stainless steel with rhodium or nickel coating over silver. The cases of HEC are made of chromate-plated brass and stainless steel.

The wires and cables are connected to the contact tails by welding, crimping, or more rarely, by soldering.

HEC are used in aviation and space technology, as well as in power plants.

The HEC that are most common in Russian industry are shown in Fig. 1, and some of their technical parameters are shown in Table 1 (USSR inventor's certificate 640441).

Insulators for non-hermetic HEC (Fig. 2) are made of ceramics. They coincide completely in their destination with the plastic insulators of electric connectors and are intended for attaching the contacts (pin, pin jack) in plugs and sockets, respectively. They ensure the following electric insulation resistance ($M\Omega$): 1000 in normal climatic conditions, 15 at increased temperature (e.g. at 300°C), and 2 after prolonged exposure to moisture. The decrease in the electrical resistance of the insulation will be mostly determined by the fastening elements: thermocements, insulation materials, etc.

In an ideal case of design, the electric connector has to transmit electric signals with minimum losses and secure their reliable transfer even after a certain number of couplings and uncouplings within the limits of the prescribed service life.

Electrical connection in a coupled connector is implemented by contact between the contacting surfaces of the pin and pin jack under a certain pressure developed by an elastic element (a spring). With the minimum possible motion of the spring, the contact pressure should provide for the required electric parameters, including the minimum value of transitional electrical resistance, whose value in a HEC can vary from 2 to 30 $M\Omega$ depending on the material of the pin and pin jack, their diameters, and the coating applied which, in turn, provides for corrosion resistance of the contacts and their high reliability, and aids in attaining stable electrical parameters.

The value of the spring contact pressure in a HEC can vary from 0.981 to 50 N depending on the pin diameter. The force for uncoupling the HEC plug and socket can range

from 22 to 200 N depending on the diameter and number of contacts.

In order to ensure stable parameters of the electric contacts of the couples (pin and jack) in coupling of plug and socket and after coupling, the pins in a perfect variant of HEC manufacture should be inserted into pin jacks and exist in a coaxially coupled state.

In practice this does not happen, which reduces contact reliability, in spite of the fact that all structural elements of HEC are manufactured in accordance with the prescribed tolerances and fits. Therefore, the positional tolerance of low-voltage and low-frequency electrical connectors in GOST 19104-88 for deviation of the insulator opening axis is acceptable within the limit of ± 0.05 mm (this is actually the permissible non-coaxiality of the opening axes, i.e., shifting of the coordinate grid of the contact arrangement in the insulator with respect to the fit diameter).

While it is possible to ensure a coordinate grid with this level of precision in plastic insulators, it is much more difficult to achieve the same in the case of HEC. It is easier to achieve it in a hermetic plug, since these plugs are produced by glass-to-metal soldering with rigid fixation of the contacts in the device. The ceramic mixtures used for non-hermetic plug and socket insulators shrink after firing, and often their shrinkage coefficients differ along axes X , Y , and Z [4-7].

These peculiarities have to be taken into account in designing and manufacturing HEC.

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